Non-classical excitation in Bose-Einstein Condenates

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To generate a non-classical states, such as Fock state, squeezed, and Cat state, is the cornerstone of the quantum optics platform to develop quantum technology, such as continue variable quantum computing. Using matter wave, instead of electro-magnetic (EM) wave, would open a new door for "quantum optics". The interaction between particles (atoms), which is absent between photons. Bose-Einstein condensate, a collective sate of particles reaching the regime with wave nature, is a promising candidate for this approach.

We present the experimental observation of macroscopic excited motional states in Bose-Einstein condensates. The interference of the states exhibits a non-gaussian density distribution. Unlike the conventional collective oscillation modes, the perturbative approach is not applicable for such dynamics. In our protocol of the trap frequency jumping, the condensate is self-excited by lowering the potential well and allowing it to release the chemical potential to the kinetic energy.

Our excitation protocol is straightforward and with on thermalization observed. In comparison with the nonclassical excitation with optical lattice and ion trap, only the projection onto the momentum space can be observed, but the in-situ density distribution function, because of the very small length scale.

To observe and enhance the obtained effects, we transferred BECs to a quasi-2D potential well with a chirped trap frequency, and then effectively converted the 3D atomic ensemble to a sequence of 2D slices. In the second stage of the adiabatic expansion, the length scale was magnified without further excitation. Therefore, we were allowed to observed the cloud deformation in details. The excited atomic cloud undergoes coherent superposition and possesses collective oscillation among excited motional states. The momentum space observation (time-of-flight imaging) provides a strong implication of squeezing. Our method can be applied for the matter-wave propagation and manipulation of nonclassical motional states.